Coastal Ocean-Atmospheric Coupled System (COACS) for the South China Sea (SCS)-a Modeling Component of the International South China Sea Monsoon Experiment (SCSMEX)

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LONG-TERM GOALS

The main goal is to establish a nowcast system for regional seas, including the South China Sea. This system will have the capability of diagnosing three dimensional velocity, temperature, and salinity fields from satellite and sparse in-situ observations. This system will be easily embedded into the prediction system (e.g., Princeton Ocean Model). The combined nowcast/forecast system will greatly enhance existing operational capability.

OBJECTIVES

This is a three-year proposal for extending the current NOMP research project (the South China Sea prediction system) to a coastal air-ocean coupled prediction system and for participating in the international South China Sea Monsoon Experiment (SCSMEX) during 1998-2002 as a modeling component. Under the current sponsorship we have developed: an optimization scheme for determining open boundary conditions, high-order difference schemes for reducing sigma coordinate error at abrupt topography, a statistical model for determining thermohaline variability, and a parametric model for obtaining physical characteristics (SST, mixed layer depth, thermocline depth, thermocline strength, ...) from vertical profiles. We propose to incorporate these new techniques into the South China Sea prediction system (POM) and to expand our modeling effort into a coastal air-ocean coupled model.

APPROACH

With the ONR support, I invited several professors and scientists from external institutions to the Naval Ocean Analysis and Prediction (NOAP) Laboratory at NPS for collaborative research.

(1) We used an optimization method to establish an open boundary diagnosis module for determining open boundary conditions from interior observations. The module was tested by the Princeton Ocean Model (POM).

(2) We used the GFDL Modular Ocean Model (MOM) to study the ocean surface flux correction and and ocean climate drift.

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(3) We proposed a series of three-point sixth-order difference schemes for coastal ocean models, and used the Semi-spectral Primitive Equation Model (SPEM) with a steep sea mount to test the advantage of using the sixth order schemes.

(4) We used the National Center for Atmospheric Research (NCAR) most recent version of the regional climate model (RegCM2) to simulate the atmospheric processes over the South China Sea during the monsoon transition.

(5) We used the Princeton Ocean Model (POM) to investigate the physical causes of the recently detected South China Sea warm-core and cold-core eddies, their transient feature, and used the NCAR RegCM2 to study the effects of the South China Sea on monsoon onset.

(6) We used covariance model and parametric model to detect the South China Sea thermohaline feature and variability. Through this work, we establish a coastal environmental assessment system.

WORK COMPLETED

(1) We developed a coastal atmosphere-ocean coupled system (CAOCS) for numerical simulation and data assimilation; (2) We discovered second kind predictability in Lorenz system and climate models; (3) We identified the oceanic response to uncertain wind forcing; (4) We identified and modeled South China Sea warm-core and cool-core eddies, and the thermohaline variability of the South China Sea, Yellow Sea, and Sea of Japan; (5) We have developed and verified various high-order difference schemes for coastal modeling; (6) We developed and tested a geometric model for obtaining physical characteristics (SST, mixed layer depth, thermocline depth, thermocline strength, ...) from vertical profiles; (7) We developed and tested an optimization method has been developed for determining the open boundary conditions of coastal models; (8) We validated the P-vector inverse method using MOM model and observational data; (9) We validated the CAOCS system for South China Sea using AXBT measurements; (10) We participated the oceanographic component of the U.S. participation in the international SCSMEX.

RESULTS

(1) A coastal atmosphere-ocean coupled system (CAOCS) is developed. The oceanic component consists of the Princeton Ocean Model (POM) with 20 km horizontal resolution and 23 sigma levels conforming to a realistic bottom topography. The atmospheric component consists of a recent version of the regional climate model (RegCM2) with 40 km horizontal resolution and 16 vertical levels. The CAOCS model was integrated for a month from 1 May 1995. The initial conditions for the atmosphere are the ECMWF analyses, and for the ocean are the model output from a forty four months' run of the stand-alone POM model forced by climatological monthly mean wind stresses, and restoring type surface salt and heat. The CAOCS model agrees well with an extensive airborne expendable bathythermograph (AXBT) survey of the South China Sea (SCS) conducted in May 1995, and shows the capability of simulating the SCS multi-eddy structure in May 1995.

(2) Error propagation from winds to ocean models was numerically investigated using the Princeton Ocean Model (POM) for the South China Sea (SCS) with 20 km horizontal resolution and 23 sigma levels conforming to a realistic bottom topography during the life time of tropical cyclone Ernie (4-18

November 1996). Numerical integration was divided into pre-experimental and experimental stages. The pre-experiment generates the initial conditions on 1 November for the sensitivity experiment. During the experimental stage, the POM was integrated from 1 to 30 November 1996 under National Centers for Environmental Prediction (NCEP) re-analyzed surface fluxes along with two surface wind data sets, namely, the daily averaged interpolated NASA Scatterometer (NSCAT) winds and the NCEP winds. The relative root-mean-square differences fluctuate from 0.5 to 1.0 for winds, from 0.25 to 0.7 for surface elevations, from 0.47 to 1.02 for surface currents, and from 0 to 0.23 for surface temperatures, respectively. This indicates that the model has less uncertainty overall than the wind fields used to drive it, which in turn suggests that the ocean modeling community may progress without waiting for the atmospheric modelers to build the perfect forecast model.

(3) The Lorenz system is used to discuss two kinds of predictability, the model sensitivity to inaccurate initial conditions (first kind) and to inaccurate boundary conditions (second kind). The first kind of predictability has been investigated for a long time, but not the second kind. We found that the Lorenz system has a capability to detect both kinds of predictability since the boundary condition is represented by a model parameter, r. Two sensitivity runs are designed by perturbing the initial condition and the model parameter r by the same small relative error 0.0001, which is equivalent to 10% of the instrumentational accuracy for surface temperature measurement. Comparison of model output between the control run and the sensitivity runs shows that the model error growth and the growing period are comparable between the two kinds of predictability. This indicates the importance of preparing accurate boundary conditions in numerical prediction.

(4) Temporal and spatial decorrelation scales were identified for the coastal seas near China. The temporal and spatial signals fluctuate according to the Asian monsoon. Variation of surface forcing from winter to summer monsoon season causes the change of the thermal structure, including the decorrelation scales.

(5) A geometric model has been developed for analyzing observed regional sea temperature profiles based on a layered structure of temperature fields (mixed-layer, thermocline, and deep layers). It contains three major components: (a) a first-guess parametric model, (b) high-resolution profiles interpolated from observed profiles, and (c) fitting of high-resolution profiles to the parametric model (Chu et al., 1997b). The output of this parametric model is a set of major characteristics of each profile: sea surface temperature, mixed-layer depth, thermocline depth, thermocline temperature gradient, and deep layer stratification. Analyzing nearly 15,000 Yellow Sea historical (1950-1988) temperature profiles (CTD: 4,825; XBT: 3,213; bathythermograph: 6,965) from the Naval Oceanographic Office (NAVOCEANO)'s Master Oceanographic Observation Data Set by this parametric model, the Yellow Sea thermal field reveals dual structure: one layer (vertically uniform) during winter, and multi layer (mixed-layer, thermocline, sublayer) during summer. Strong seasonal variations were also found in mixed-layer depth, thermocline depth, and thermocline strength.

(6) The South China Sea warm-core/cool-core eddies were identified using the Navy's MOODS data as well as the National Meteorological Center (NCEP) sea surface temperature (SST) fields (1982-94).

(7) The σ-coordinate, pressure gradient error depends on the choice of difference schemes. By choosing an optimal scheme, we may reduce the error in a great deal without increasing the horizontal

resolution. Analytical analysis shows that the truncation error ratio between the fourth-order scheme and the second-order scheme is proportional to Δ^2 , and the truncation error ratio between the sixth-order scheme and the second-order scheme is proportional to Δ^4. Here Δ is the grid spacing. We used the Semi-Spectral Primitive Equation Model (SPEM) to demonstrate the benefit of using the sixth-order scheme. We also created a series of three-point sixth-order finite difference schemes for ocean models.

(8) Haney-type surface thermal boundary conditions connect net downward surface heat flux to air/sea temperature difference (gradient-type condition) or to climate/synoptic sea temperature difference (restoring-type condition). On the basis of cross-correlation and variance analyses on the NCEP net downward surface heat flux and air/sea temperature data during 1 October 1994 - 31 December 1995, we obtain the following results: (I) The restoring-type conditions do not represent the surface thermal forcing anywhere in the world oceans. (ii) For the equatorial and subtropical oceans, the gradient-type conditions are not good approximations for the surface thermal forcing. (iii) For the middle and high latitudes away from coasts, the gradient-type conditions are good approximation for the surface thermal forcing. This is based on the high correlation between net downward heat flux and air/sea temperature difference and associating quasi-steadiness of the coupling coefficient. Furthermore, there is a better correlation when the solar short wave component is treated separately. (iv) A value of 70 $Wm^{-2}K^{-1}$ for the coupling coefficient is suggested for northern (southern) middle and high latitude zones, no matter whether the data is smoothed or un-smoothed. The suggested values are about twice as it was generally used (10-50 $Wm^{-2}K^{-1}$). This might increase the net air-sea heat flux and shorten the relaxation time.

(9) We found an interdecadal oscillation in a wind and thermally driven OGCM. The oscillation is tantalizing in that it occurs under a thermal damping (26.3 $Wm^{-2}K^{-1}$). Detailed examinations involving a two-dimensional OGCM, a simple thermal “flip-Flop” model, and a three-dimensional OGCM with and without the nonlinear effect of temperature in the state equation demonstrate that the oscillation is not driven by mechanisms that exhibit in the so-called convective oscillator, or the advective overshooting oscillator. Instead, the oscillation is associated with the propagation of modeled viscous boundary waves along the weakly or non stratified boundaries. It was found that a long north-south basin extent is conductive to the generation of meridional flows normal to the weakly or non stratified boundary. These flows are crucial for the generation of persistent oscillations.

(10) We demonstrated that an incompatibility between a surface temperature climatology and a given ocean model, into which the climatology is assimilated via Haney restoration, can cause model ocean climate drift and interdecadal oscillations when the ocean is switched to a weaker restoration. This is done in an idealized Atlantic Ocean model driven by thermal and wind forcing. Initially, the temperature climatology is forcefully assimilated into the model, and an implied heat flux is diagnosed. During this stage any compatibility is suppressed. The restoring boundary condition is then switched to a new forcing consisting of a part of the diagnosed flux and a part of the restoring forcing in such a way that at the moment of the switching the heat flux is identified to that prior to the switching. Under this new forcing condition, the incompatibility becomes manifest, causing changes in convection pattern, and producing. Under this new forcing condition, the incompatibility becomes manifest, causing changes in convection patterns, and producing drift and interdecadal oscillations.

IMPACT/APPLICATIONS

The current work leads to accurate coastal modeling.

TRANSITIONS

(1) The parametric and statistical models has been transferred to the Naval Oceanographic Office for MOODS data processing. (2)The South China Sea model results were utilized in designing the oceanographic component of the international SCSMEX. (3) The high-order difference schemes were distributed to the ocean modeling community. (4) The open boundary module was used by the oceanographic community.

RELATED PROJECTS

(1) International South China Sea Monsoon Experiment (SCSMEX). The current project is the U.S. oceanographic component of SCSMEX.

(2) Littoral Zone Ocean Prediction project sponsored by the Naval Oceanographic Office.

(3) Ocean modeling project (Australian Department of Environment, Sport, and Territories) sponsored my collaborator, Dr. Wenju Cai.

(4) Monsoon disturbances over southeast ans east Asia and adjacent seas (PI, Dr. C.-P. Chang) sponsored by the ONR Marine Meteorology Program.

PUBLICATIONS (REFEREED)

Chu, P.C., S.K. Wells, S.D. Haeger, C. Szczechowski, and M. Carron: "Temporal and spatial scales of the Yellow Sea thermal variability," Journal of Geophysical Research, 102, 5655-5668, 1997.

Chu, P.C., C.R. Fralick, S.D. Haeger, and M.J. Carron, "A parametric model for Yellow Sea thermal variability," Journal of Geophysical Research, 102, 10499-10508, 1997.

Chu, P.C., C.W. Fan, and L.L. Ehret, "Determination of open boundary conditions from interior observational data," Journal of Meteorological and Oceanic Technology, 14, 723-734, 1997.

Chu, P.C., and C.P. Chang, "South China Sea warm pool", Advances in Atmospheric Sciences, 14, 195-206, 1997.

Chu, P.C., H.C. Tseng, C.P. Chang, and J.M. Chen, "South China Sea warm pool detected from the Navy's Master Oceanographic Observational Data Set (MOODS), Journal of Geophysical Research, 102, 15761-15771, 1997.

Chu, P.C., S.H. Lu, and Y. Chen, "Temporal and spatial variabilities of the South China Sea surface temperature anomaly" Journal of Geophysical Research, 102, 15761-15771, 1997.

Chu, P.C., and C.W. Fan, "Sixth-order difference scheme for sigma coordinate ocean models," Journal of Physical Oceanography, 27, 2064-2071, 1997.
Steger, J., C.A. Collins, and P.C. Chu, 1998:" Circulation in the Archipelago de Colon (Galapagos Islands), November 1993," Deep Sea Research, in press.

Cai, W.J., and P.C. Chu, "A thermal oscillation under a restorative forcing," Quarterly Journal of the Royal Meteorological Society, 124, 793-809, 1998.

Chu, P.C., Y.C. Chen, and S.H. Lu, On Haney-type surface thermal boundary conditions for ocean circulation models. Journal of Physical Oceanography, 28, 890-901, 1998.

Chu, P.C., C.W. Fan, and W.J. Cai, "Evaluation of P vector method using modular ocean model (MOM)," Journal of Oceanography, 54, 185-198, 1998.

Chu, P.C., Y.C. Chen, S.H. Lu, "Temporal and spatial variabilities of Japan Sea surface temperature and atmospheric forcings" Journal of Oceanography, in press, 1998.

Chu, P.C., and C.W. Fan,"A three-point combined compact difference scheme," Journal of Computational Physics, 140, 370-399, 1998.

Cai, W.J., and P.C. Chu, "Oceanic responses to gradual transitions of equator-to-pole temperature gradients," Quarterly Journal of the Royal Meteorological Society, in press, 1998.

Chu, P.C., S.H. Lu, and Y.C. Chen, "Wind-driven South China Sea deep basin warm-core /cool-core eddies," Journal of Oceanography, 54, 347-360, 1998.

Chu, P.C., C.W. Fan, C.J. Lozano, and J. Kerling, "An AXBT survey of the South China Sea," Journal of Geophysical Research, 103, 21637-21652, 1998.

Chu, P.C., and C.W. Fan, Improvement of estuarine and coastal modeling using high-order difference schemes. Estuarine and Coastal Modeling, 5, American Society of Civil Engineering, 28-34, 1998.

Chu, P.C., Q.Q. Wang, and R.H. Bourke, "A geometric model for Beaufort/Chukchi Sea thermohaline structure", Journal of Atmospheric and Oceanic Technology, in press, 1998.

Chu, P.C., S.H. Lu, and W.T. Liu, "Uncertainty of the South China Sea prediction using NSCAT and NCEP winds during tropical storm Ernie 1996," Journal of Geophysical Research, in press, 1998.

Chu, P.C., and C.W. Fan, "Compact difference scheme for sigma coastal ocean models," Quarterly Journal of the Royal Meteorological Society, submitted, 1998.

Chu, P.C., Y.F. Qian, and L.L. Ehret, "Wind generated South China Sea warm-core/cool-core eddies," Journal of Geophysical Research, in revision, 1998.

Chu, P.C., and N.L. Edmons,: "A three-dimensional numerical simulation of the South China Sea circulation and thermohaline structure." Chinese Journal of Atmospheric Sciences, in press, 1998.

Chu, P.C., and C.W. Fan,"A three-point non-uniform combined compact difference scheme," Journal of Computational Physics**,** 140, resubmitted after revision, 1998.
Chu, P.C., Two kinds of predictability in Lorenz system. Journal of the Atmospheric Sciences**,** resubmitted after revision, 1998.

Chu, P.C., and C.W. Fan, "Determination of sub-surface thermal structure from satellite SST observation. Journal of Physical Oceanography**,** in revision, 1998.

Chu, P.C., and N.L. Edmons,: "Dynamical mechanisms for the South China Sea seasonal circulation and thermohaline variabilities." Journal of Physical Oceanography**,** in revision, 1998.

Chu, P.C., A. Kuninaka, and Y.C. Chen, Air-sea interactions and thermohaline structure of East China Sea/Yellow Sea. Journal of Geophysical Research, in revision, 1998.

Chu, P.C., S.H. Lu, and Y.C. Chen, A coastal atmosphere-ocean coupled system (CAOCS) for simulating South China Sea multi-eddy structure, May 1995. Journal of Geophysical Research, submitted, 1998.

Chu, P.C., and J. M. Veneziano, Response of the South China Sea to tropical cyclone Ernie 1996. Journal of Physical Oceanography**,** in revision, 1998.

Chu, P.C., S.H. Lu, and Y.C. Chen, Second kind predictability in climate models. Tellus**,** submitted, 1998.

Chu, P.C., S.H. Lu, and Y.C. Chen, Simulation of summer monsoon onset over east Asia with a NCAR regional climate model. Monthly Weather Review, submitted, 1998.

Chu, P.C., Y.C. Chen, and S.H. Lu, Japan/East Sea (JES) polar front meandering and eddy shedding detected from an airborne expandable bathythermograph survey, May 1995. Journal of Geophysical Research, submitted, 1998.

PUBLICATIONS (PROCEEDINGS)

Chu, P.C., S.H. Lu, and Y.C. Chen,"Response of radiative fluxes to tiny random sea surface temperature disturbances," 9th Conference on Atmospheric Radiation**,** American Meteorological Society, 124-127, 1997.

Chu, P.C., S.H. Lu, and Y.C. Chen,"Response of hydrological cycle to tiny random sea surface temperature disturbances," 13th Conference on Hydrology**,** American Meteorological Society, J45-J47, 1997.

Chu, P.C., S.H. Lu, and Y.C. Chen,"Evaluation of ice-albedo effect by a coupled atmosphere-ocean model ," 9th Symposium on Interaction of the Sea and Atmosphere**,** American Meteorological Society, 142-145, 1998.

Chu, P.C., and C.W. Fan, "High-order difference schemes for coastal modeling," Second Conference on Coastal Oceanic and Atmospheric Prediction**,** American Meteorological Society, 68-73, 1998.

Chu, P.C., S.H. Lu, and Y. Chen, "Second kind predictability in climate models," 9th Symposium on Global Change, American Meteorological Society, 86-90, 1998.

Chu, P.C., S.H. Lu, and Y. Chen, "Effects of the Drake Passage on the global climatic change," 9th Symposium on Global Change**,** American Meteorological Society, 261-265, 1998.

Chu, P.C., "Naval Ocean Analysis and Prediction (NOAP) **-** an integrated education and research program at the Naval Postgraduate School", 7th Conference on Education**,** American Meteorological Society, 117-180, 1998.

Chu, P.C., S.H. Lu, and Y.C. Chen, "Simulation of spring to summer monsoon transition over east Asia with an NCAR regional climate model," Monsoon and Hydrological Cycle**,** Korean Meteorological Society, 155-159, 1998.

Web site: http://vislab-www.nps.navy.mil/~chu/noap.html